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MASS PRODUCTION TECHNOLOGY FOR GENETICALLY IMPROVED FAST GROWING FOREST TREE SPECIES

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POSSIBLE MASS PRODUCTION OPTIONS FOR *ACACIA MANGIUM* PLANTATIONS IN SABAH (MALAYSIA)

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Acacia mangium is considered as a major re-afforestation species in Sabah by virtue of its capacity in rehabilitating degraded sites and its remarkable growth potential. Consequently, it is a matter of urgency to think about the most appropriate mass production options to fulfill the immediate needs and the increasing demands for planting stock. Despite an obvious lack of information on breeding features of the species due to its very recent domestication, substantial gains can be expected from simple strategies based on seed propagation, taking full advantage of the fact that *Acacia mangium* is a very early prolific seed producer and responds quite satisfactorily to provenance selection. Mass clonal propagation, on the other hand, appears to be severely handicapped by the negative effects of maturation process on the ability for true-to-type cloning of the selected genotypes.

An attractive solution should consist of Family Plus Within-Family Selection of the best provenances or land races refined by Progeny Testing, then using vegetative propagation techniques to establish clonal seed orchards as production populations from the selected Elite individuals.

Acacia mangium est considéré comme une espèce majeure de reboisement au Sabah pour ses capacités à réhabiliter les sites dégradés et sa croissance remarquable. En conséquence, il est urgent de déterminer les options les plus appropriées de production de biomasse pour remplir les besoins immédiats et la demande croissante de plants de reboisement. Malgré une absence totale d'information sur les modalités d'hybridation de l'espèce due à sa très récente domestication, des gains substanciels peuvent être attendus de stratégies simples basées sur la reproduction sexuée, prennant en compte le fait qu'*Acacia mangium* est une espèce se reproduisant très tôt et abondamment et répond de façon satisfaisante à la sélection de provenance. D'un autre côté, la propagation clonale est handicapée par des effets négatifs de maturation sur les possibilités des clonages des génotypes sélectionnés.
Une solution intéressante pourrait consister en la sélection de familles-plus parmi des familles de la meilleure provenance au races définies par des tests de descendance, puis utilisant la propagation végétative pour établir des vergers de clones comme populations de production des arbres d'élite sélectionnés.

1. INTRODUCTION

Sabah, one of the 13 states that constitute the Federation of Malaysia, is located in the northern part of Borneo, between latitude 4-7° North and longitude 115-119° East. The climate is typically tropical humid with mean annual rainfall ranging between 1500 and 4000 mm -depending on the location-, and equable temperature of 25 to 30 °C throughout the year.

With a total area of 73 711 km², Sabah remains sparsely populated with about 1.8 M. inhabitants mainly concentrated on coasts and in towns.

The economy is based on the export of natural resources, especially timber.

Nearly 37 000 km² are covered by forests - 51 % of the total area -, but among them 3 900 km² only are legally allowed for industrial re-afforestation under 3 main companies, which are investing a lot in *Acacia mangium* due to its attractive characteristics.

2. CHARACTERISTICS AND POTENTIALITY OF *ACACIA MANGIUM* FOR SABAH

Acacia mangium Willd., belonging to Leguminosae (Mimosoideae), is native to northern Queensland (NQ) in Australia, western parts of Papua New Guinea (PNG) and eastern Indonesian provinces of Irian Jaya and Maluku, between 1° and 19° of southern latitude and for an altitude varying from sea level up to 720 m (Gunn and Midgley 1991).

It has been recognized as a valuable exotic since its initial introduction into Sabah in 1966, where it has thrived on a rather wide range of soils, including very acid and infertile ones. It demonstrates a valued ability to rehabilitate degraded lands, whose fertility can be restored through its nitrogen fixing ability resulting from a natural symbiosis with *Rhizobium*. In such site conditions, it outperforms all the other fast growing species, especially in case of proliferating weeds such as *Imperata cylindrica* and *Eupatorium odoratum* with which it competes successfully. The early vigorous growth of this short-lived pioneer enables it to reach commonly 20-25 m in height within 10-15 years in Sabah, with a wood production averaging 25-30 m^3/ha/year (Sim 1986), despite the mediocre genetic value of the planted material.

The wood produced, with a basic density of 420 kg/m^3, seems preferentially recommendable for pulping, with characteristics at least as good as some of the commercially accepted high-quality eucalypts (Logan 1986), and reconstituted boards. It has also been considered to be adapted to various other uses including plywood and sawlogs (Mead and Miller 1991).

This specific potential account for the extensive plantations in Sabah reaching 20 000 ha today, with the support of international organizations like FAO and the World Bank. However, restriction of allocated areas for industrials plantations will require intensification of management to improve the productivity of the planted areas.

3. CURRENT STATUS OF *ACACIA MANGIUM* BREEDING APPLIED TO SABAH

31. AVAILABILITY OF GENETIC RESOURCES

The original population of *Acacia mangium* introduced in Sabah in 1966 was restricted to a sole half-sib family collected from one tree growing close to Mission Beach, in northern Queensland (Jones and Tham 1980). Until the early 1980s, which corresponds to the introduction of new origins, most of the *Acacia mangium* plantations carried out in Sabah originated from 300 of these half-sib individuals planted in Ulu Kukut, or from subsequent derived generations, up to the fifth, in total absence of any selection (Jones and Tham 1980, Sim 1984).

Such a policy led as might be expected to a steady degradation over the successive generations of the quality of the plantations (Sim 1984), resulting probably from the depression due to excessive inbreeding levels within this species, which is usually recognized as outcrossing.

Introductions of other genetic origins from the natural range into Sabah began in 1978 in the form of provenance, then provenance/progeny trials, as summarized in the Appendix. The first evaluations indicated that, in addition to the desirability of widening the narrow original genetic base, substantial gains can be expected from native sources. Among them, Far North Queensland (Claudie River), and PNG provenances or sub-provenances (Skelton 1981) performed quite satisfactorily (Sim and Gan 1991), with special reference for Oriomo origins which displayed the greatest vigor, as reported in Table. Furthermore, since 1980, 107 different accessible populations including 39 from Papua New Guinea (PNG) have been collected by the Australian

<u>Table</u>: HEIGHT M.A.I. (m/yr) FOR *A. MANGIUM* PROVENANCES IN SABAH

Trial sites	Age	INDONESIA	AUSTRALIA (QUEENSLAND)		PAPUA NEW GUINEA	INDONESIA
		Ceram	Cairns Reg.	Far North	West. Prov.	Irian Jaya
[1] Sabah Forest Industries						
Site A	4	3.80	3.13	3.64	-	3.60
Site C	3	4.15	3.92	4.19	4.22	3.99
Site D	3	3.52	3.44	3.69	-	3.31
[1] SAFODA Bengkoka	4	-	2.98	-	3.27	2.68
[2] Silam plot 10	3	-	4.27	5.70	5.03	-
	6*	-	3.27	3.80	3.33	-
	8	-	3.22	3.80	3.47	-
[3] Luasong						
Plot 1 PNG	1	-	-	-	4.89 (27.0)	-
Plot 2 PNG	1	-	-	-	4.51 (26.2)	-
Plot 3 PNG	1	-	-	-	5.00 (24.4)	-
Plot 1 QLD	1	-	3.22 (39.1)	3.81 (34.9)	-	-
Plot 2 QLD	1	-	-	3.79 (37.5)	-	-
Plot 3 QLD	1	-	3.34 (36.8)	3.98 (33.2)	-	-

* After 70% thinning

Values in brackets indicate coefficient of variations in %

[1] Ref: HARWOOD & WILLIAMS (1992)

[2] NASI & GANING (1990): ICSB/CTFT internal report

[3] NASI (1991): unpublished data

Tree Seed Centre - ATSC, CSIRO Division of Forestry - which coordinates the genetic resource activities for *Acacia mangium* (Gunn and Midgley 1991).

Concerning the specific genetic diversity, it should be mentioned that despite a noticeable variation evident from field trials and plantations, isozyme analyses revealed overall low genetic variability within the species, with only slight differences with respect to the origins (Moran et al. 1989).

32. ABILITY FOR HYBRIDIZATION

Acacia mangium exhibits naturally a good ability for inter and *a fortiori* intra-specific hybridization. The most demonstrable occurrences refer to the identification of *Acacia mangium* X *Acacia auriculiformis* hybrids which do not express however so outstanding hybrid vigor. Although some other characteristics might be advantageous, such as a wider site adaptability than *A. mangium* and improved wood properties (Pinso and Nasi 1992), its real interest, especially from an economical point of view, requires further investigation.

33. TRAITS DESIRED FOR SELECTION AND GENETIC PARAMETERS

Objectively, in view of pulpwood utilization, growth capacity and density, as they determine the yield of raw material, have to be considered as the most important traits for selection. Additionally and if necessary, they could be combined with more specific wood characteristics for optimizing pulp and paper manufacturing, and form traits.

However, it should be emphasized that due to the very recent interest for *Acacia mangium*, there is still an evident lack of elementary knowledge despite that the first progeny trials were set in 1981 near Sandakan by the Forest Research Center of Sepilok. Little or no information is available regarding basic genetic parameters, such as the most frequent crossing system type and the resulting self or out-cross fertilization ratios - in spite of the species being classified as andromonoecious - (Zakaria and Kamis 1991), the inheritance of major selected traits, breeding values,... Even the assessment of the natural genetic variability seems to require further investigation.

With such little advanced knowledge about this quite recently domesticated tree species, a largely pragmatic breeding strategy appears to be the wisest and the most rational policy.

34. ECONOMICAL CONSTRAINTS

As already mentioned, the activities related to *Acacia mangium* in Sabah currently are mainly supported by 3 major companies, namely: Sabah Forest Industries (SFI, private status), Sabah Softwood Sdn Bhd (SSSB, private status) and Sabah Forestry Development Authority (SAFODA, state status), to which only a restricted area had been devoted.

In addition, the situation of developing country that characterizes Sabah at the present time strongly incites the investors to look basically for maximum short-term returns with minimal inputs.

These obvious constraints based on economic considerations place limits to the development of pure or long-term research activity and account for the actual policy which concentrates preferentially on short-term profitable strategies. This has to be fully considered when analysing the most appropriated plant mass production options for improving *Acacia mangium* plantations in Sabah today.

4. ADVANTAGES AND LIMITATIONS OF PROPAGATION BY SEEDS

41. GENETIC DIVERSITY AND GENETIC IMPROVEMENT

The basic feature of propagation by seeds is to create new genotypes while increasing the number of individuals from original parent(s).

Benefitting from this major attribute of sexual propagation appears objectively most recommendable for *Acacia mangium* in Sabah today to enrich the originally quite restricted genetic potential.

At the initial step, special attention has to be devoted to the constitution of the first base populations to take advantage of the already existing natural intra-specific variability at different levels - provenances, populations, families,...- with the ever-remaining possibility to discover remarkable outstanding individuals whose genetic value could be further exploited. Whatever strategy adopted, the efficiency of the genetic improvement of *Acacia mangium* in Sabah will be greatly influenced by the nature of the genetic components of the first base populations.

More concretely, and for a proper management of the genetic resources, the followings remarks can be taken into consideration:

* a substantial gain can be expected from initial provenance selections (Harwood and Williams 1992). As an illustration, PNG provenances established in Silam display at age 9 a superiority of 30-40% in vigor over the overall provenance mean;

* first generation of local seed sources tends to outperform the original native provenances they derived from (Sim 1984);

* *Acacia mangium* responds quite satisfactorily to simple methods of breeding, such as phenotypic mass selection followed by intensive culling (90%), even when applied to genetically common or poor already existing populations before conversion into seed stands;

* it may tolerate some degree of self-compatibility (Sedgley et al. 1992), occurring naturally probably due to its flower morphology and flowering phenology, but whose critical range is still unknown;

* inbreeding depression symptoms appear in the extreme case of several successive generations of self-crossing from a very genetically restricted original population, as happened for the original single half-sib family first introduced in Sabah.

42. DELAYS

In contrast to a lot of forest tree species, *Acacia mangium* enters the reproduction phase early, since individuals begin to produce seeds at about 18 month old in Sabah, to become fully productive at 3 to 4 year-old.

Consequently:

* the time period required before harvesting seeds to supply the demands is short;

* these short reproductive cycles would lead to rapid progress in genetic improvement and breeding programmes, through the possibility for instance to achieve selections based on progeny testing earlier.

43. QUANTITIES

Acacia mangium is rightly recognized as a prolific seed producer, especially in Sabah where seeds are produced twice a year, in January and in July. As an illustration, 1.5 kg of seeds per tree on average have been harvested annually from trees growing quite naturally in Silam, since they reached 5 year-old, without any measure aiming to increase the seed yield, as would be the case for true seed production areas. Although seeds from PNG were found to be bigger and heavier than those coming from North Queensland (80 000 to 100 000 versus 100 000 to 120 000 per kg, on average), it can be assumed that, once reaching the mature stage, each tree can provide enough seedlings to plant annually around 70 to 80 ha over a 20-25 year period. This can probably be indefinitely extended using vegetative propagation methods.

Quantitatively speaking, propagation by seeds therefore represents a huge potential.

44. QUALITY

Evidently, the quality will depend mainly of the breeding value the parents the seedlings are issued from. As already noticed, the most serious risks for *Acacia mangium* so far seem to be the use of seeds from highly inbred populations resulting from several successive inbreeding generations, and the risk of using an inferior provenance or land-race derived from an inferior provenance.

Field trials in Silam and Luasong at age 3 and 1 years respectively demonstrate acceptable within-provenance and within-progeny overall variability in height (as expressed by the coefficient of variation values in Table). Some individuals nevertheless display outstanding growth capacity with height increment of more than 110% over the family mean, and warrant further testing before a possible exploitation through cloning.

The possibility of enhancing the quality of seedling populations is likely to be through a better control of between parent crosses, which requires information not yet available, such as Specific Combining Ability. Furthermore, as previously mentioned, individual self-pollination rate and the way it affects vigour remains still unknown. This may warrant control pollination, irrespective of the costs...

It should be added that *Acacia mangium* seeds, once properly treated, usually display high germination rates - 90% and over - (Doran and Gunn 1986) and can be stored for several years without any deleterious effect.

45. COSTS

Presently, the commercialization values of good seed sources collected from open-pollinated trees reach about 1000 Malaysian $/kg for Sabah origins, and 600 to 800 Australian $/kg when coming from northern Queensland seed stands and Papua New Guinea. These are average prices, with possible variations in quantity of seeds per kg according to the origins, as above-mentioned.

Considering:

* that Sabah origins demonstrate comparable or even superior potential than the imported lots - which may argue for the land race concept - ,

* that labor costs required for seed stands maintenance and seed harvesting are much more lower in Sabah than in Australia,

* the consignment costs,

* the profit margins,

there is a great interest for a Sabah plantation agency to have its own *Acacia mangium* seed production area(s).

Regarding controlled-pollination, the extremely low efficiency of the current techniques (Sedgley et al. 1992) leading to the highly expensive production of a very restricted quantity of seeds refutes its use for mass producing plants. In the case of really worthwhile offspring -which has still to be proved- the only alternative could be through the relay of adapted vegetative propagation methods.

5. WHAT CAN BE EXPECTED FROM THE VEGETATIVE PROPAGATION OPTION

The basic feature of asexual or vegetative propagation by contrast with sexual propagation through seeds consists, throughout mitosis, in duplicating individuals while preserving their whole genetic identity and structure. This means, in terms of plant improvement, capturing and transferring to the asexually obtained offspring the integral genetic value -both additive and non-additive components- of the donor tree they derived from.

Vegetative propagation can be applied to a group of mixed genotypes without maintaining any individual identification, referred to below as "Bulk propagation", or to originally selected genotypes preserving their individual identity through successive propagation cycles: referred to as the clonal propagation option. Both can be considered to mass propagate *Acacia mangium*.

51. BULK PROPAGATION

The main interest for bulk propagation consists of vegetatively mass propagating a restricted quantity of juvenile genotypes of presumably high and similar genetic value, derived for example from control pollination. The more juvenile the plant material, the more responsive to vegetative propagation and the easier to succeed at lover cost through the use of cuttings.

Although proved to be feasible (Wong and Haines 1992), the possible restrictions for large scale application to *Acacia mangium* are:

* to make sure that the quantitatively restricted genotypes being considered for propagation display real outstanding genetic potential relative to more abundantly available ones;

* possible disadvantages in plantations - survival rates, growth habit, settling capacity, longevity,...-, or for subsequent utilizations, of plants produced from cuttings by comparison with seedlings, irrespectively to their genetic value;

* the costs of production which are definitely higher than in case of seedlings obtained from open pollination, rejecting the possibility to reduce the costs through several successive rotations of harvesting because coppicing ability is inadequate;

* specific limits for vegetative propagation, including the multiplication rates and the ability for adventitious rooting of the cuttings, which are much lower for *Acacia mangium* than for *Acacia auriculiformis* (see Wong and Haines 1992);

* the length of time the plant material can be bulk propagated without displaying prejudicial maturation effects affecting the quality - Wong and Haines' studies indicated a decreasing trend of mean root number from the first to the fifth cycle-, the quantity and the cost of the production;

* the possible narrowing of the original genetic base when advancing in successive generations especially through serial - or sequential (Wong and Haines 1992)- propagation of rooted cuttings from the initial population, due to genotypic difference in vegetative propagation capacity, with the resulting potential dangers of a too restricted genetic base;

* eventual loss in genetic gain as a consequence of this unavoidable selection for vegetative reproduction ability.

As has been done for other species (maritime pine at AFOCEL for instance), one should analyze and check very realistically and carefully these different points before opting for mass production of *Acacia mangium* using bulk propagation, which does not present the same advantages as the clonal option.

52. CLONAL PROPAGATION

The expected advantages of cloning for *Acacia mangium* were recently considered by Haines and Griffin (1992), who stated the superiority of the clonal option when applied to genotypes selected first from best families or advanced generation families, whose value was subsequently confirmed through rigorous clonal testing.

In the same way as for many forest species, the two following options can be considered for operational production of selected *Acacia mangium* clones:

- Option 1:

1) phenotypic selection of sufficiently developed superior -and generally already mature- individuals;

2) rejuvenation, with possible resort to adapted tissue culture techniques;

3) clonal testing

4) mass clonal propagation

- Option 2:

1) broad mass selection at an early stage of development corresponding to great capacity for vegetative propagation;

2) maintenance through appropriated nursery techniques -hedging, serial cuttings- or tissue culture technology -cold storage- of this high ability for cloning, regardless of time course;

3) in the meanwhile, setting comparative clonal tests to rogue progressively the inferior genotypes from the initial population;

4) mass clonal production of the selected genotypes.

However, there are restrictions for the applications of these scenarios.

The clonal option basically requires time to carry out the genotypic selections including the clonal tests. The time required acts negatively through the maturation process on the ability for true-to-type cloning of selected material through cuttings. This factor, whose intensity may vary according to the genotype, must not be underestimated in *Acacia mangium* (Darus et al. 1990, CTFT unpublished results) and can give rise to additional and more constraining limitations than those already mentioned for the bulk propagation option, especially regarding the difficulties:

* for option 1, in rejuvenating the selected individuals, with quite variable capacity for producing stump sprouts once the tree has been felled, and overall low efficiency of nursery techniques to achieve this goal (Haines et al. 1992, CTFT/ICSB unpublished results);

* for option 2, in maintaining the original cloning ability during the time required to carry out the clonal testing - which could be determined by juvenile-adult correlations, not yet available.

Consequentially, possible genotype-dependent variations in capacity of reaching or maintaining the "physiological juvenile status" required to produce high fidelity copies may lead to unreliable clonal selection, primarily for reproductive traits rather than economic ones, resulting in a reduction of the genetic gain (Haines and Woolaston 1991).

Subsequently, by increasing inter- and intraclonal variability, the negative influence of maturation on capacity for true-to-type cloning can affect the overall quality of the mass clonal production.

Apart from these aspects, a lot of other components have to be considered, such as the site adaptability of the selected clones owing to heterogeneous environmental conditions in Sabah, the number of clones finally selected to constitute the production population, the dynamics of the clonal strategy in terms of new selections and replacements,...

Whatever the option chosen, the resulting costs can be definitely prohibitive, without the possibility of extending the production period by harvesting, on a coppicing rotation, several times from the same stump.

This requires us analyze accurately in terms of economical gains the magnitude of individual genotypic potential as compared to what can be expected from a group of several genotypes mixed together.

Thus, although theoretically highly recommendable, there are objectively severe limitations for mass clonal propagation of *Acacia mangium* in Sabah, at least for the present time, until new strategic information becomes available.

Another alternative is to consider clonal propagation as a means of producing clones for establishing clonal seed orchards. In that case, most of the above mentioned limitations are not important - especially the required high ability for true-to-type cloning through cuttings. This undertaking has already been demonstrated to be quite feasible, despite the low rates of success in air-layering - "marcottes" - proved to be nevertheless the most efficient technique so far to clone selected mature individuals.

6. CONCLUSION - STRATEGY PROPOSAL

From the foregoing it appears that in spite of an obvious lack of information on breeding features of *Acacia mangium* due to its very recent domestication, substantial gains can be expected from simple strategies based on seed propagation.

Mass clonal propagation on the other hand seems to be severely handicapped by the negative effects of maturation process on the ability for true-to-type cloning of the selected genotypes.

Considering these basic features, the economic constraints and the urgency to meet the immediate and the increasing demands for planting stocks, a possible mass production option is proposed in Figure, assuming vigor as the most important selection trait. Its general lines consist of:

1) starting from already proven best provenances -PNG, NQ- including a large quantity of different populations - sub-provenances, populations *sensu stricto*, families - as base populations, established with special care to avoid too much spatial contiguity between siblings. Preference will be given to totally randomized one-tree-plot or randomized complete-block designs, with one or a very few of siblings per plot.

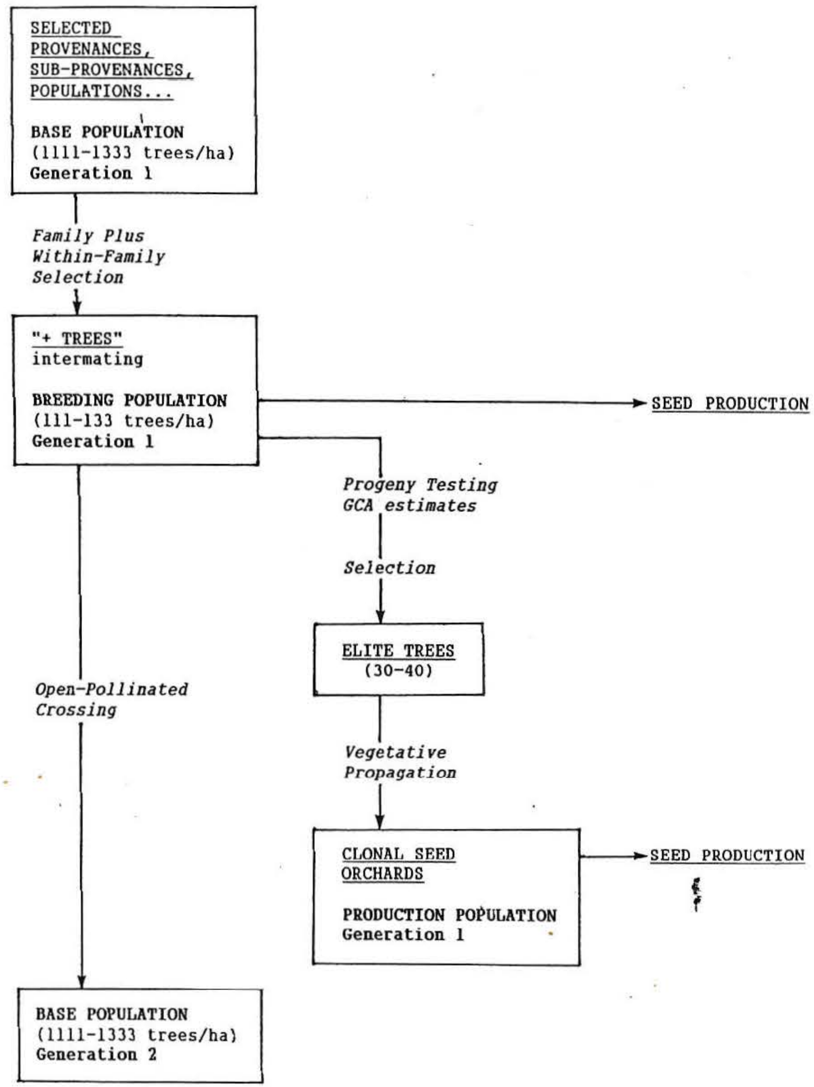
2) carrying out Family Plus Within-Family Phenotypic Selection to keep only one individual per elementary plot, to limit inbreeding resulting from siblings intermating. The thinned stand constitutes the breeding population, which could also supply seeds for operational planting if required.

3) "Plus trees" of this breeding population can be further tested through their progeny, taking advantage of the specific short generation time, while providing a rough estimate of general combining ability at the same time. The genotypes retained from the ultimate selection will constitute the production population. They will be vegetatively propagated by marcottes to create clonal seed orchards, from which the clones strongly disadvantaged by unfavorable site X genotype interaction could be rogued.

This scheme, although not particularly original, seems quite adapted to the mass production of *Acacia mangium* in Sabah in the current context, taking into consideration both the restricted advances so far in specific knowledge and the particularities of the country.

Furthermore, its flexibility should enable it to adapt or to take full advantage of any interesting result emerging from current or future research.

Figure: STRATEGY PROPOSAL FOR MASS PRODUCTION OF *ACACIA MANGIUM* IN SABAH



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Appendix: INTRODUCTIONS OF A. MANGIUM IN SABAH

Country	Locality	Date *	Locations in Sabah
Indonesia	Cililin	1987	Mandahan
	Piru	1984	Kolapis A, Telupid, Sipitang, Bengkol
	Sidei	1984	Kolapis A, Telupid, Sipitang
Papua New Guinea	Balamuk	1982	Kolapis A, Brumas, Sook, Telupid, Silam, Mandahan
	Bandaber	1989	Luasong
	Bensbach–Balamuk Rd	1989	Luasong
	Bimadebun	1989	Luasong
	Boite	1988	Sipitang
	Derideri	1989	Luasong
	Dimisisi	1989	Luasong
	Gubam Boite	1989	Luasong
	Iokwa	1982	Kolapis A, Brumas, Sook, Telupid, Silam, Mandahan
	Mai Kussa	1989	Luasong
	Mibini Village	1989	Luasong
	Oriomo River	1982	Kolapis A, Brumas, Sook, Telupid, Silam, Mandahan, Kota Belud, Bongkol, Luasong
	Pongaki	1989	Luasong
	South of Keru	1989	Luasong
	Toko	1982	Kolapis A, Brumas, Sook, Silam, Mandahan
	Wemenever	1988	Sipitang
Queensland	Abergowrie	1982	Brumas, Sook, Silam, Bongkol
	Ayton	1989	Luasong
	Broken Pole Creek	1984	Kolapis A, Brumas, Sook, Telupid, Sipitang, Bongkol
	Cardwell	1981	Kolapis B, Brumas
	Cardwell, Ellerbeck	1984	Brumas, Sook, Bongkol, Mandahan
	Cassowary Range	1980	Kolapis B, Brumas, Telupid, Sipitang, Mandahan
	Claudie River (FNQ)	1982	Kolapis A, Brumas, Sook, Telupid, Silam, Mandahan, Kota Belud
	Cowley Beach	1984	Kolapis A, Telupid, Sipitang
	Daintree	1981	Kolapis B, Brumas, Sipitang
	Euluma Creek	1980	Brumas
	Ingham	1989	Luasong
	Julatten	1981	Kolapis B, Brumas
	Mission Beach	1967	Kolapis B, Brumas
	Mossman	1980	Kolapis B, Brumas, Sook, Bongkol
	Mourilyan Bay	1984	Kolapis B, Brumas, Bongkol
	N.W.Lockhart River (FNQ)	1989	Luasong
	Olive River (FNQ)	1984	Kolapis A, Brumas, Telupid, Kota Belud
	Rex Range	1981	Kolapis B, Sipitang
	Shelburne Bay	1989	Luasong
	S.W. Cairns	1989	Luasong
	Tully Mission	1982	Kolapis B, Brumas, Silam, Sipitang, Bongkol
	Walsh's Pyramid	1982	Kolapis B, Brumas, Sook, Silam, Sipitang, Mandahan
	Whyanbell Creek	1980	Brumas

* first introduction trial in Sabah

Locations & Relevant authorities

Sipitang (Sabah Forest Industries)
Brumas (Sabah Softwood Sdn. Bhd.)
Silam, Luasong (Rakyat Berjaya Sdn. Bhd.)
Kolapis A & B, Sook, Telupid (Forest Research Centre)
Mandahan, Bongkol, Kota Belud (Sabah Forestry Development Authority)